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**TECHNETIUM-99, IODINE-129 AND TRITIUM
IN THE WATERS OF THE SAVANNAH RIVER SITE^(U)**

D.M. Beals and D.W. Hayes

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Technetium-99, Iodine-129 and Tritium in the Waters of the Savannah River Site

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Abstract

Surface water samples were collected from streams on and around the Savannah River Site, (SRS) to assess current ^3H , ^{99}Tc , and ^{129}I concentrations in the water. The SRS is a nuclear facility operated by Westinghouse Savannah River Company for the US Department of Energy. Water quality parameters were measured at the time of collection using field portable instrumentation. The tritium activity was determined by liquid scintillation spectrometry. The isotopes, ^{99}Tc and ^{129}I , were determined by isotope dilution/inductively coupled plasma-mass spectrometry [1,2].

Elevated activities of ^3H , ^{99}Tc , and ^{129}I were found in some surface streams of the SRS, principally due to migration of ground water from beneath old seepage basins, however the levels in the waters leaving the SRS are well below any regulatory guidelines.

Introduction

The Savannah River Site, located along the Savannah River in western South Carolina (Figure 1) was built and began production of nuclear materials in the 1950's. The primary mission of the SRS was to produce tritium and plutonium for the national defense program. However, the primary mission of the site at this time is environmental restoration and remediation. All reactor facilities are either shut down or placed in standby status. During the years of operation low levels of radioactive elements were released to the atmosphere and surface water, including seepage basins, of the SRS. These radioactive elements included uranium, plutonium and tritium [3], as well as the waste products ^{14}C , $^{89,90}\text{Sr}$, ^{99}Tc [4], $^{129}\text{I}^-$ [5], $^{134/137}\text{Cs}$, and others.

To ensure the safety of the site workers, surrounding communities and downstream water supplies, the levels of radionuclides discharged from the SRS have been continuously monitored. Technetium exists as the very mobile TcO_4^- ion in oxidizing environments [6] and is known to concentrate in the thyroid and GI tract [7]. Iodine may exist as the reduced I^- or the oxidized IO_3^- and concentrates in the thyroid of mammals. Due to the low specific activity of ^{99}Tc and ^{129}I , (half lives of 2.12×10^5 and 1.57×10^7 years, respectively) they have been difficult to monitor in the surface waters of the SRS. The Savannah River Technology Center, (SRTC) at the SRS has recently developed simplified procedures to measure ^{99}Tc and ^{129}I in

aqueous samples by isotope dilution/inductively coupled plasma-mass spectrometry, (ID/ICP-MS) [1,2].

In this study, the current concentration of ^3H , ^{99}Tc and ^{129}I was examined in the surface waters of the SRS to assess the impact of the SRS releases on the environment. This, is the largest data set compiled on ^{99}Tc and ^{129}I activities in the surface waters of the SRS. Grab samples were collected during winter, (high flow) and summer, (low flow) over a period of 2 to 3 years. The ^3H activity was determined by liquid scintillation spectrometry, and the ^{99}Tc and ^{129}I were determined by ID/ICP-MS.

Samples were collected from five different watersheds on the SRS and from one offsite creek, (Figure 2A and 2B). Hollow Creek was chosen as a control background watershed. It receives no discharge from the SRS. The Upper Three Runs, (U3R) watershed is the only SRS stream system to originate offsite. South Carolina state Highway 278 runs along the northern boundary of the SRS; Tyler Bridge Road, SRS Road 2.1, is also above site activities. Therefore both sampling locations, Highway 278 and Road 2.1, along U3R and Tinker Creek, should also serve as background sampling locations. Tinker Creek conjoins with U3R above SRS Road F. Crouch Branch receives a small amount of discharge from the H separation area seepage basins and from the Solid Waste Disposal Facility, (SWDF). It enters U3R below Road F and above the confluence of U3R and Tim's Branch. Tim's Branch drains Steed Pond which is known to have elevated concentrations of uranium in the sediment [8]. Sampling point #5 on Tim's Branch is just prior to Tim's Branch entering U3R. The junction of U3R and Tim's Branch is at the SRS Road C crossing. Beginning in 1988, low level radioactive waste process water from the SRS was treated by the Effluent Treatment Facility, (ETF) prior to release rather than being discharged, (as previously done) directly to seepage basins. The ETF treatment process is not capable of removing ^3H and has a low decontamination factor for Tc. The discharge from the ETF enters U3R just below SRS Road C. The sampling points at Road A, (South Carolina state Highway 125) and at Box Landing Road are below the ETF and are the last samples collected prior to U3R entering the Savannah River.

From 1954-1988 the seepage basins, several of which were located near the F and H separation areas, were used for the disposal of wastewater containing low concentrations of chemicals and radionuclides. Radionuclides released to the seepage basins included ^3H , ^{99}Tc and ^{129}I . The seepage basins were intended to delay the release of radionuclides offsite by adsorption on the clay layers beneath them and allowing time for radioactive decay. Use of the seepage basins was discontinued in 1988 when the ETF was brought on line. The seepage basins were capped and sealed in 1990. Water beneath the F- and H-area seepage basins migrates with the flow of the groundwater, eventually outcropping into Fourmile Branch, which drains to the Savannah River.

Fourmile Branch originates near the middle of the SRS. Road F crosses Fourmile Branch near its headwaters. The Road F and Road E-1 crossing of Fourmile Branch are above aqueous input from SRS activities. Migrating water from the H separation area seepage basins

enters Fourmile Branch above Road C. Migrating water from the F separation area seepage basins enters Fourmile Branch below the Road C crossing. While the C reactor was operating, secondary cooling water from the reactor was discharged to Fourmile Branch above the A-7 sampling point. The Road A sampling point is the last sample collected prior to Fourmile Branch entering the Savannah River flood plain.

Pen Branch does not receive any SRS aqueous discharge prior to the Road B sampling point. Indian Grave Branch carried secondary cooling water from the K reactor, (a tritium production reactor now being shut down) to Pen Branch. Indian Grave currently receives migrating groundwater from below the K area seepage basin. The Road A sampling point of Pen Branch is below the confluence of Indian Grave with Pen Branch. Below this point, Pen Branch enters the Savannah River swamp. It mixes with Steel Creek just prior to entering the Savannah River.

The headwaters of Steel Creek are at the P area reactor outfall. The first sample along Steel Creek was collected just below the outfall. During the years of reactor operation Steel Creek received effluent discharges from both L and P reactors. L Lake was built in 1985 to provide cooling for the L reactor thermal discharges by damming Steel Creek. At that same time, P reactor effluents were diverted to a seepage basin. Steel Creek currently receives migrating water from the P area seepage basin. Samples were also collected from Steel Creek in L Lake, at the top of the lake during one sampling period, and the outfall from the lake in all sampling periods, and at Road A, prior to mixing with Pen Branch and entering the Savannah River.

The last stream system sampled was the Lower Three Runs Creek system, (L3R). Par Pond was formed by damming L3R, and received cooling waters from P and R reactors. To improve cooling of reactor effluent, several other small ponds were constructed; Pond B in the headwaters of L3R is the largest of these. Samples were collected in Pond B, Par Pond at the bubble up, (where new water is introduced to Par Pond from Pond C) and several locations below the Par Pond dam. At this time there are no direct discharges from SRS activities to the L3R system.

Methods

Sample Collection Samples were collected at the desired locations by dipping 2L polyethylene bottles below the surface of the water. The bottles had been rinsed with distilled and deionized water in a class 10,000 clean laboratory, (less than 10,000 particles per cubic foot) prior to use, and were rinsed with the sample water several times prior to filling and sealing the bottle. Field measurements of water quality were made at the time of sample collection. Samples were stored refrigerated at 4°C until analysis. All sample processing was performed in a class 10,000 clean laboratory; all analyses were performed on a aliquot of the sample from the same bottle. The ICP-MS is housed in a class 1000, (less than 1,000 particles per cubic foot) clean facility; the LSC in a class 10,000 facility. Reagent grade chemicals were

used for the iodine determinations, ultrapure nitric acid, (Seastar Chemicals, Seattle WA, USA) was used for the technetium analyses.

Instrumentation

A Turner Spectrometry SOLA ICP-MS (now marketed by Finnigan MAT) was used for detection of ^{99}Tc and ^{129}I . The SOLA is equipped with an automatic sampler and CETAC ultrasonic nebulizer for sample introduction. Tritium activities were determined on a Packard Tri-Carb 2050A liquid scintillation spectrometer with automatic quench correction. Water quality parameters were measured in the field at the time of sample collection using a Horiba U-10 water quality meter.

Procedures

Technetium-99 Typically a one litre sample is used for the ^{99}Tc determination. A ^{97}Tc tracer is added to the sample for isotope dilution analysis. The sample is heated in the presence of hydrogen peroxide to equilibrate the tracer with the sample and to ensure that the Tc is in the oxidized form. Technetium is then extracted from the sample using TEVA-Spec extraction chromatography material, (EiChroM Industries, Darien IL, USA). Technetium is strongly retained from neutral pH solutions by the material, while the isobaric interfering elements of Mo is only weakly retained and Ru is not retained at all. Molybdenum has several isotopes, one of which is mass 97, which is 9.5% of natural abundance; ruthenium, also multiisotopic, has a 12.7% abundant peak at mass 99. Technetium may be removed from the extraction material using dilute nitric acid which is injected into the ICP-MS for isotope ratio determination [1].

The custom elemental equation written into the SOLA software corrects the $m/z=97$ peak for any remaining Mo based on the $m/z=95$ peak, assuming natural mass abundances of the Mo isotopes. The $m/z=99$ peak is corrected for any remaining Ru based on the $m/z=101$, again assuming natural abundances of the Ru isotopes. The $m/z=99$ correction is usually negligible, (Figure 2A) however the $m/z=97$ correction may be significant in some samples, (Figure 2B). The 99/97 ratio is measured using the multiplier detector of the SOLA set at a dwell time of 16 msec/channel, 16 channel/amu, 50 passes per scan. Four scans are performed during each sample analysis. A five minute rinse, using a solution of 1% nitric acid, is performed between each sample analysis.

Iodine-129 The initial procedure development to analyze ^{129}I by ICP-MS used a Meinhardt nebulizer and Scott's spray chamber for sample introduction. We were not able to eliminate the xenon interference at $m/z=129$, (26.4% abundant peak of natural xenon) in aqueous samples, (Figure 3A) thus we had to develop a concentration procedure to achieve our desired detection limit of less than 37 mBq/L, (1 pCi/L)[2]. With the substitution of a CETAC ultrasonic nebulizer for sample introduction the Xe interference was no longer apparent, (Figure 3B). The lack of xenon in the sample spectra when using the ultrasonic nebulizer vs the Meinhardt

nebulizer for sample introduction may be due to the different mass flow conditions of the carrier gas, changing the plasma characteristics, thus ionizing the xenon contaminant of the argon gas less efficiently under the ultrasonic nebulizer flow conditions, [9]. We are still using the sample concentration procedure prior to analysis to lower our detection limit even further. Sample analysis for determination of ^{129}I requires two ICP-MS measurements. The natural iodine, (^{127}I) concentration is measured in the original sample using indium as an internal standard. This value is then used as the tracer concentration for the isotope dilution calculation. After adjustment of the oxidation state the iodine is extracted onto an anion exchange resin, (AG 1X8, chloride form, BioRad Laboratories, Richmond CA, USA). The iodine is then eluted from the resin with dilute nitric acid which is injected into the ICP-MS for isotope ratio determination.

The m/z 129/127 ratio is measured within a few days of sample preparation to minimize iodine loss from the nitric acid solution. The 129/127 ratio is multiplied by the measured iodine, (^{127}I) concentration to determine the ^{129}I concentration in the sample. The 129/127 ratio is often measured using the multiplier detector of the SOLA set at a dwell time of 16 msec/channel, 16 channel/amu, 50 passes per scan. Four scans are performed during each sample analysis. For samples with high natural iodine concentrations both the Faraday detector and the multiplier detector of the SOLA are used, [2]. The ^{127}I count rate is measured on the Faraday detector and the ^{129}I on the multiplier, with indium used as a normalizing factor to determine the 129/127 ratio. A five minute rinse, using a solution of 1% nitric acid, is performed between each sample analysis.

Tritium The tritium concentration of the samples was determined by liquid scintillation spectrometry (LSC). Three milliliters of sample were pipetted into a 25 ml plastic scintillation vial. Nineteen milliliters of Opti-fluor liquid scintillation cocktail were added to each sample. Samples were counted three times, ten minutes each count, using the blank correction and automatic quench correction curves of the Tri-Carb counter.

Results

The results from the analyses completed during this study are shown in Tables 1-5. The pH, conductivity and temperature were recorded in the field at the time of sample collection. The reported ^3H results are the mean of the three LSC counts. The mean ^3H results had an average relative standard deviation, (RSD) of less than 5% and so are not reported in the tables, (individual counting errors often were greater than the 5% RSD but were not propagated). The ^{99}Tc and ^{129}I activities are calculated based on the mean of the four scans completed for each sample analyzed by the ICP-MS. The error associated with the ^{99}Tc data is the standard deviation of the mean; it is due to the variation in the scan results only. The ^{129}I error incorporates the standard deviation on the 129/127 measurement as well as the standard deviation on the iodine, (^{127}I) concentration measurement.

The large error associated with much of the ^{99}Tc and ^{129}I data is due to the concentration being close to the detection limit of the technique. The detection limit of the procedure for ^{99}Tc , based on a one litre sample, is below .02 Bq/L (0.5 pCi/L); the mean and standard deviation, (one sigma) of several reagent blank samples run concurrently with these samples was 0.013 ± 0.004 Bq/L (0.35 ± 0.11 pCi/L). This study was designed as a scoping study of the surface waters of the SRS, thus this detection limit was sufficient. The Savannah River Technology Center, (SRTC) also has a procedure to determine ^{99}Tc by Positive Thermal Ionization Mass Spectrometry PTI-MS, [10]. The instrumental detection limit for ^{99}Tc by PTI-MS is 0.03 mBq/L (0.7 fCi/L). The procedural detection limit, based on a series of samples collected in the Arctic, is 0.3 mBq/L (8 fCi/L) based on a 1L sample [11].

Because the concentration of the tracer enters into the calculation of detection limit for isotope dilution techniques, it is not so straight forward to state a detection limit for the ^{129}I measurement. The iodine concentration of the streams sampled during this study varied from 1-30 ppb depending on sample location and season. The SOLA ICP-MS is capable of measuring a 129/127 ratio as small as 10^{-10} ; typical reagent blank 129/127 ratios of 10^{-5} were measured concurrently with these samples, while typical sample ratios were 0.01 to 0.001. If the five sample locations expected to have no influence from the SRS operations, (iodine concentration from 1-7 ppb) are used to estimate a detection limit for this study, the average ($n=21$) is 0.022 Bq/L (0.60 pCi/L), suggesting the detection limit for ^{129}I based on this procedure using a one liter sample is slightly over 0.02 Bq/L (0.5 pCi/L).

Due to the large errors on the individual sample results only general conclusions can be drawn regarding ^{99}Tc and ^{129}I in the surface waters of the SRS. The stream system most influenced by SRS activities is the Fourmile Branch system. The H-3 concentration below the F and H seepage basin inflows is over 100 times greater than the headwaters of the stream. Elevated ^3H concentrations were also found in Indian Grave Branch, and above background levels of ^3H were found in Steel Creek and occasionally in Upper Three Runs Creek, (U3R) below the ETF. The highest ^{99}Tc and ^{129}I activities were found in Fourmile Branch.

To better understand the data generated during this study, the results were averaged over the 2-2 1/2 year study period. Figures 5-7 plot the mean concentration of ^3H , ^{99}Tc and ^{129}I in the streams for all analyses completed, for which at least three samples were analyzed, versus the sampling location. The results are plotted in the same order as which the data is presented in the tables; top to bottom is presented left to right. Note that the ^3H data is plotted on a logarithmic scale, (Figure 5) while the ^{99}Tc and ^{129}I are plotted on a linear scale, (Figure 6 and 7, respectively). The first five sample locations are above the SRS influence and can be considered a background level to which the other data can be compared. These are the Hollow Creek location and the U3R and Tinker Creek samples collected at both Highway 278 and Road 2.1.

As seen in Figure 5, there are several locations where an increase in the ^3H concentration is obvious. Below the ETF on U3R, (sample locations 9 and 10) there appears to be an increase

in the ^3H concentration to almost double the background levels. As stated earlier the ETF process can not remove H-3 from the wastewater it processes and so this is not unexpected. As seen in the individual data sets, (Tables 2-5) the ^3H in U3R below the ETF is sporadic. ETF releases processed water in batches to U3R, the releases lasting less than one day, occurring every few weeks, resulting in occasional ^3H concentration increases. There does not appear to be any increase in ^{99}Tc concentration in the stream system below the SRS activities, including the ETF, (Figure 6). It has been noted in the past that the ^{129}I concentration in the U3R below SRS activities is slightly higher than above the SRS; this is thought to be due to atmospheric deposition of ^{129}I released from the separation areas stacks [5]. In this study we did find higher ^{129}I concentrations in the lower U3R, especially at Box Landing Road, (Figure 7, sample location 10).

Elevated ^3H , ^{99}Tc and ^{129}I in Fourmile Branch can be attributed to migrating groundwater from below the F- and H-area seepage basins. Fourmile Branch, below Road 4, (sample location 13) is influenced by the migrating groundwater from below the seepage basins. The groundwater is known to have a higher conductivity and contains elevated ^3H . Based on 1985-1987 averages, approximately 8.9×10^{13} Bq/L (2400 Ci/yr) of ^3H migrate from the F-area seepage basins, approximately 2.2×10^{14} Bq/L (6000 Ci/yr) from the H-area seepage basins [3]. Technetium-99 has been detected in the groundwater of several F and H area seepage basin monitoring wells. Along the seepeline, ^{99}Tc concentrations of up to 44.4 Bq/L (1200 pCi/L) and 10.36 Bq/L (280 pCi/L) were measured below F and H area basins, respectively [4]. Below the F area seepeline, ^{129}I concentrations as high as 15.17 Bq/L (410 pCi/L) have been measured; as high as 1.85 Bq/L (50 pCi/L) below the H area seepeline [5]. The headwaters of Fourmile Branch also appear to have excess ^3H possibly due to atmospheric deposition and surface runoff within the upper Fourmile Branch. Technetium-99 and ^{129}I do not appear elevated above the seepage basin inflows.

The ^3H concentration in Indian Grave is influenced by groundwater from the K area seepage basin, while Pen Branch at Road B, (sample location 17) appears to receive little aqueous ^3H input. After mixing with Indian Grave the ^3H concentration of Pen Branch significantly increases, (sample location 19). The ^{99}Tc concentration in the stream system does not appear to vary greatly with season or location. The average ^{99}Tc concentration may increase slightly downstream. The ^{129}I concentration in Pen Branch at both sampling locations appears higher than in Indian Grave, however this conclusion is supported by only one of the four sampling periods.

The ^3H concentration in Steel Creek is significantly above background levels in all sample locations. There appears to be a sporadic input of ^3H , probably from P area, which is then well mixed in L Lake and the lower Steel Creek system, (sample location 22 and 23). Technetium-99 may be being introduced to Steel Creek from P area as is ^3H . The average ^{99}Tc concentration in Steel Creek below P area, (sample location 20) appears slightly higher than the concentration in L Lake and lower Steel Creek. Elevated ^{99}Tc was found in two monitoring wells downgradient from the L area Oil and Chemical Basin. Due to the large dilution

effect no ^{99}Tc in excess of the normal background levels was found in L Lake. The amount of variation in ^{129}I concentration in the Steel Creek samples is similar to the variation in the above SRS samples thus it may not be significant.

Tritium concentrations in Pond B and Par Pond are slightly above background. Below the Par Pond dam, ^3H concentrations are decreased in L3R by dilution due to increasing water flow between the dam and the Savannah River. No input of ^{99}Tc or ^{129}I was detectable from operations of the SRS in the entire L3R system.

Conclusions

Elevated concentrations of ^3H , ^{99}Tc or ^{129}I were measured in some surface waters of the SRS. The higher concentrations were associated with ground water migration from beneath old seepage basins. The seepage basins were used for the disposal of waste water containing low concentrations of chemicals and radionuclides from the SRS operations and were closed in 1988. The SRS streams carrying the radionuclides discharge into the Savannah River. After mixing with the Savannah River, all radionuclide concentrations are well below any applicable regulatory guidelines.

Previous to this study, few measurements of ^{99}Tc or ^{129}I in surface streams of the SRS existed, principally due to the difficulty in measuring these isotopes. The developed technique is rapid, (samples can be processed in batches, six analyses per hour can be analyzed by the ICP-MS protocol) and offers detection limits suitable for environmental monitoring requirements.

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Figure 1. Map showing location of the Savannah River Site

Figure 2A. Savannah River Site Surface Water Sample Locations

Figure 2b. Savannah River Site Surface Water Sample Sites and Description of Location

Number	Sample Location	Sample Description
1	Hollow Creek	off site background
Upper Three Runs Creek system (U3R)		
2	Tinker Ck @ Hwy 278	above site activities
3	Tinker Ck @ Road 2.1	above site activities
4	U3R @ Hwy 278	above site activities
5	U3R @ Road 2.1	above site activities
6	U3R @ Road F	below mix of U3R & Tinker Creek
7	Tim's Branch	prior to enter U3R
8	U#R @ Road C	above ETF outfall
9	U3R @ Road A	below ETF outfall
10	U3R @ Box Landing Road	below site activities
Fourmile Branch system (4MB)		
11	4MB @ Road F	headwater
12	4MB @ Road E—1	above seepage basins
13	4MB @ Road 4	below H seepage basins
14	4MB @ Road C	below F seepage basins
15	4MB @ Road A—7	below C reactor discharge
16	4MB @ Road A	below site activities
Pen Branch system (PB)		
17	PB @ Road B	above K reactor
18	Indian Grave @ Road B	below K seepage
19	PB @ Road A	below mix of Indian Grave & PB
Steel Creek system (SC)		
20	SC below P	headwater, P reactor outfall
21	SC @ Road B	top of lake
22	L Lake outfall	below dam
23	SC @ Road A	prior to mix with PB
Lower Three Runs Creek system (L3R)		
24	Pond B	cooling for P & R reactor
25	bubble up	inflow to Par Pond
26	L3R @ road B	below Par Pond dam
27	L3R @ Donora Station	below site activities
28	L3R @ Patterson Mill	below site activities
29	L3R @ Hwy 125	prior to entrance to Savannah River

Figure 3A Typical Sample Spectra for ^{99}Tc without Molybdenum Interference

Figure BA Typical Sample Spectra for ^{99}Tc with Remaining Molybdenum

Figure 4A. Typical Sample Spectra for ^{129}I Analysis using a Meinhart Nebulizer

Figure 4B. Typical Sample Spectra for ^{129}I using the CETAC Ultrasonic Nebulizer

Figure 5. Tritium concentration plotted against sample location.

Figure 6. Technetium-99 concentration plotted against sample location.

Figure 7. Iodine-129 concentration plotted against sample location.

Table 1. Savannah River Site Sample Collection Sites And Results
Collection Dates: July 1992

Sampling Site	I-129		Tc-99	
	Bq/L	% RSD	Bq/L	% RSD
11	0.001	82	0.008	5
12	0.001	119	0.007	17
13	0.085	55	0.115	81
14	0.080	38	0.076	71
15	0.041	40	0.115	59
16	0.011	25	0.028	40

Table 2. Savannah River Site Sample Collection Sites And Results
Collection Dates: 18 January - 1 February 1993

Sampling Site	pH	conduct. mS	temp. °C	³H Bq/ml	¹²⁹I Bq/mL	RSD %	⁹⁹Tc Bq/L	RSD %
1	6.72	0.016	11.9	0.032	0.026	25	0.015	100
1	6.72	0.016	11.9	0.026	0.017	37	0.013	51
2	6.17	0.022	9.9	0.019	0.008	29	0.007	118
3	5.97	0.017	9.7	0.044	0.027	53	0.028	87
4	5.28	0.012	11.6	0.020	0.011	24	0.015	129
6	5.87	0.014	10.3	0.061	0.010	26	0.011	44
7	6.09	0.038	13.0	0.049	0.009	23	0.012	23
8	5.59	0.015	11.2	0.079	0.013	32	0.008	41
9	5.98	0.015	11.0	0.061	0.022	52	0.010	37
11	5.39	0.017	9.6	0.103	0.028	26	0.010	18
12	5.38	0.015	11.4	0.115	0.015	17	0.022	16
13	5.99	0.046	11.8	1.530	0.015	24	0.035	35
14	6.02	0.047	11.4	4.375	0.012	16	0.025	35
15	5.95	0.050	11.2	15.774	0.016	10	0.021	56
16	6.22	0.044	11.7	10.020	0.016	12	0.032	32
17	6.55	0.036	8.1	0.156	0.025	15	0.030	70
18	6.91	0.040	9.0	1.793	0.017	10	0.019	23
19	6.16	0.040	11.5	2.308	0.018	25	0.026	110
20	7.15	0.048	12.0	0.131	0.012	42	0.007	37
22	6.99	0.052	9.9	0.275	0.016	18	0.009	41
23	6.29	0.051	12.4	0.250	0.015	8	0.012	75
24	6.87	0.014	12.7	0.140	0.017	33	0.010	10
24	7.41	0.038	12.9	0.083	0.007	50	0.011	118
27	6.17	0.038	11.5	0.090	0.017	35	0.009	76
28	6.28	0.046	12.0	0.087	0.009	21	0.018	100
29	6.27	0.043	11.2	0.035	0.009	42	0.012	49

Table 3. Savannah River Site Sample Collection Locations And Results
Collection Dates: 15 - 16 July 1993

Sampling Site	pH	conduct. mS	temp. °C	³ H Bq/ml	¹²⁹ I Bq/mL	RSD %	⁹⁹ Tc Bq/L	RSD %
1	6.08	0.012	23.4	0.017	0.001	101	0.010	25
1	6.08	0.012	23.4	0.022	0.003	74	0.011	24
2	6.32	0.032	27.6	0.058	0.015	65	0.020	12
3	6.04	0.021	24.2	0.045	0.006	60	0.017	7
4	5.96	0.011	21.7	0.036	0.019	47	0.015	12
5	5.66	0.011	22.1	0.014	0.009	58	0.020	8
6	6.29	0.042	22.9	0.034	0.005	104	0.017	38
7	6.69	0.108	22.0	0.039	0.006	109	0.014	17
8	5.59	0.015	23.2	0.038	0.003	115	0.015	26
9	6.08	0.022	23.6	0.051	0.005	22	0.021	20
10	6.23	0.018	23.7	0.053	0.009	60	0.020	14
11	6.46	0.078	26.2	0.154	0.016	102	0.013	3
12	6.39	0.026	32.1	0.108	0.004	103	0.030	11
13	6.84	0.093	27.1	3.229	0.010	27	0.030	8
14	6.65	0.095	27.7	5.900	0.015	62	0.026	10
15	6.49	0.069	24.9	26.754	0.043	19	0.030	50
16	6.65	0.059	25.6	10.856	0.023	28	0.022	19
17	6.83	0.060	25.1	0.067	0.002	72	0.011	65
18	6.89	0.081	25.5	2.619	0.004	150	0.014	22
19	7.40	0.076	27.6	2.427	0.005	102	0.016	8
20	6.89	0.093	25.9	2.761	0.023	14	0.016	67
22	7.19	0.060	29.3	0.218	0.009	101	0.016	14
23	6.91	0.061	28.5	0.225	0.009	55	0.025	15
24	6.24	0.017	29.6	0.093	0.007	94	0.014	28
25	6.73	0.073	28.8	0.056	0.002	46	0.013	24
27	7.01	0.044	27.7	0.065	0.004	89	0.014	5
28	7.16	0.044	25.3	0.053	0.007	104	0.012	6
29	7.31	0.108	25.3	0.035	0.005	103	0.013	14

Table 4. Savannah River Site Sample Collection Locations And Results
Collection Dates: 7 - 9 February 1994

Sampling Site	pH	conduct. mS	temp. °C	³ H Bq/ml	¹²⁹ I Bq/mL	RSD %	⁹⁹ Tc Bq/L	RSD %
1	7.61	0.015	13.9	0.057	0.078	37	0.013	23
2	8.38	0.027	16.5	0.011	0.061	57	0.023	71
3	7.61	0.020	15.3	0.021	0.065	40	0.009	56
4	7.40	0.012	15.9	0.021	0.031	43	0.006	64
5	7.45	0.013	16.0	0.015	0.026	44	0.009	55
6	8.34	0.016	14.3	0.023	0.054	38	0.006	54
7	8.05	0.112	15.2	0.025	0.086	36	0.021	49
8	8.20	0.017	14.6	0.052	0.040	47	0.008	60
9	7.55	0.019	12.8	0.272	0.049	37	0.010	24
10	7.61	0.020	14.4	0.075	0.109	32	0.012	42
11	7.37	0.042	16.0	0.134	0.013	20	0.010	45
12	7.15	0.024	16.7	0.112	0.045	46	0.008	21
13	7.88	0.049	18.0	4.440	0.025	48	0.015	39
14	7.81	0.065	18.1	5.283	0.023	73	0.017	27
15	7.82	0.065	14.9	16.951	0.081	30	0.023	12
16	7.83	0.055	11.7	9.071	0.032	40	0.013	47
17	7.95	0.038	12.8	0.006	0.057	61	0.007	52
18	8.20	0.083	11.8	1.684	0.037	77	0.030	41
19	7.95	0.069	10.5	1.626	0.119	57	0.026	31
20	8.36	0.060	13.2	0.021	0.027	36	0.025	80
22	8.15	0.066	9.8	0.238	0.028	58	0.012	45
23	8.07	0.067	9.4	0.230	0.029	39	0.013	116
24	8.92	0.015	12.8	0.065	0.064	35	0.013	78
25	8.65	0.067	13.0	0.047	0.060	46	0.021	32
26	8.13	0.050	9.5	0.097	0.099	40	0.012	34
27	8.28	0.050	10.4	0.051	0.029	24	0.013	41
28	8.15	0.059	10.4	0.039	0.054	39	0.009	14
29	9.00	0.055	10.9	0.006	0.044	54	0.008	10

Table 5. Savannah River Site Sample Collection Locations And Results
Collection Dates: 6 - 7 June 1994

Sampling Site	pH	conduct. mS	temp. °C	³H Bq/ml	¹²⁹I Bq/mL	RSD %	⁹⁹Tc Bq/L	RSD %
1	6.78	0.012	22.2	0.015	0.014	34	0.003	53
2	7.55	0.033	25.5	0.027	0.014	7	0.004	11
3	7.45	0.022	22.5	0.022	0.002	47	0.005	17
4	7.30	0.010	21.0	0.022	0.010	52	0.004	19
5	7.18	0.011	21.3	0.018	0.021	28	0.008	4
6	7.57	0.015	21.8	0.072	0.023	52	0.010	130
7	7.85	0.057	21.6	0.035	0.019	26	0.007	33
8	7.41	0.016	21.9	0.043	0.010	48	0.011	69
9	7.23	0.025	22.1	0.179	0.008	48	0.004	2
10	7.31	0.018	22.4	0.385	0.014	28	0.003	4
11	7.01	0.032	25.7	0.073	0.026	24	0.006	1
12	7.34	0.023	25.2	0.100	0.017	28	0.004	6
13	7.17	0.047	24.5	0.693	0.032	30	0.011	19
14	6.99	0.061	24.8	3.041	0.019	48	0.018	63
15	7.50	0.057	24.1	10.813	0.036	35	0.022	6
16	7.59	0.041	23.1	10.383	0.025	24	0.028	23
17	7.74	0.045	23.3	0.053	0.026	17	0.007	38
18	7.88	0.097	24.4	1.877	0.019	40	0.004	62
19	7.80	0.084	23.0	1.795	0.011	17	0.004	29
20	7.98	0.097	24.3	0.122	0.019	20	0.021	116
21	7.95	0.072	27.1	0.309	0.009	56	0.005	10
22	7.99	0.070	25.3	0.260	0.026	42	0.011	89
23	7.86	0.071	24.7	0.259	0.052	23	0.005	28
24	7.67	0.016	27.1	0.098	0.005	37	0.003	9
25	7.85	0.090	26.1	0.022	0.027	40	0.004	17
26	7.78	0.050	24.1	0.058	0.062	20	0.003	28
27	7.80	0.053	24.0	0.059	0.070	3	0.005	38
28	7.89	0.069	22.8	0.036	0.007	59	0.005	58
29	7.82	0.077	22.9	0.029	0.021	55	0.004	47